RESEARCH DEPARTMENT

A COMPARISON OF TWO FLARE-REDUCING METHODS IN CONVENTIONAL CATHODE-RAY TUBES

Report No. T-075

(1960/19)

K. Hacking, B.Sc.

(A.B. Howe)

Report No. T-075

A COMPARISON OF TWO FLARE-REDUCING METHODS IN CONVENTIONAL CATHODE-RAY TUBES

July 1960

Report No. T-075

(1960/19)

A COMPARISON OF TWO FLARE-REDUCING METHODS IN CONVENTIONAL CATHODE-RAY TUBES

SUMMARY

The intensity profile of the familiar "halation" ring pattern associated with conventional cathode-ray tubes has been measured. From these data the relative efficiency of two flare-reducing methods has been deduced. The methods are compared on the basis of the relative flare intensity produced at the centre of a circular unexcited phosphor patch surrounded by uniformly illuminated phosphor.

1. INTRODUCTION

It is well known[1,2] that the contrast in pictures generated, directly or indirectly, by conventional cathode-ray tubes is limited mainly by the extraneous light reflected on to the phosphor by the glass/air interface of the tube. The spread profile and intensity of the flare light surrounding a single excited phosphor is influenced by several factors.[1] Some of these factors, such as the amount of phosphor contact, the faceplate thickness and the reflection coefficient of the phosphor are determined by considerations of tube manufacture and performance in respects other than that of flare. There are, however, two obvious ways in which flare might be reduced for a given tube design. These are to increase the total light absorption of the faceplate and/or to reduce the internal reflection coefficient of the glass/air interface. Both methods have been tried[1,3] and proved to be effective to some degree. The measurements and deductions reported here are aimed at providing a quantitative assessment of their relative merits.

2. FLARE INTENSITY PROFILE

This was measured by photographing the familiar concentric ring pattern obtained when a spot of phosphor is intensely excited. The zinc oxide phosphor of a flying-spot scanning tube* was used for the experiment, and the stationary electron beam was focused to give a spot size approximately 1 mm in diameter. A lens with a low veiling-glare index was used to image the phosphor screen of the tube on to a photographic plate. A piece of neutral filter material (optical density, 3·2) was placed on the tube faceplate so that one edge just covered the excited spot. This highly attenuated the brightness of the spot relative to the flare surround originating from it, and was done to minimize halation effects in the photographic plate and flare effects in the lens. The ring pattern on the developed negative was scanned by means of a microdensitometer, and the density of the negative was determined as a function

* This tube had a clear flat face about 5 mm thick.

of the distance from the central spot. The measurements were then translated into intensity units, and Fig. 1 shows the type of flare intensity profile obtained. This curve exhibits a series of peaks, corresponding to the bright rings, at distances from the centre that are in the ratio of 1 : 2 : 3. The unit of distance, which determines the horizontal scale of Fig. 1, has been chosen to make the abscissae of the peaks equal to 1, 2 and 3 units, respectively. (As will appear in Section 3, one of these units is approximately equal to $2t \tan \theta_c$, where t is the faceplate thickness and θ_c is the critical angle.) The numbers in parentheses alongside the peaks (corresponding to the consecutive rings) denote their relative intensities.

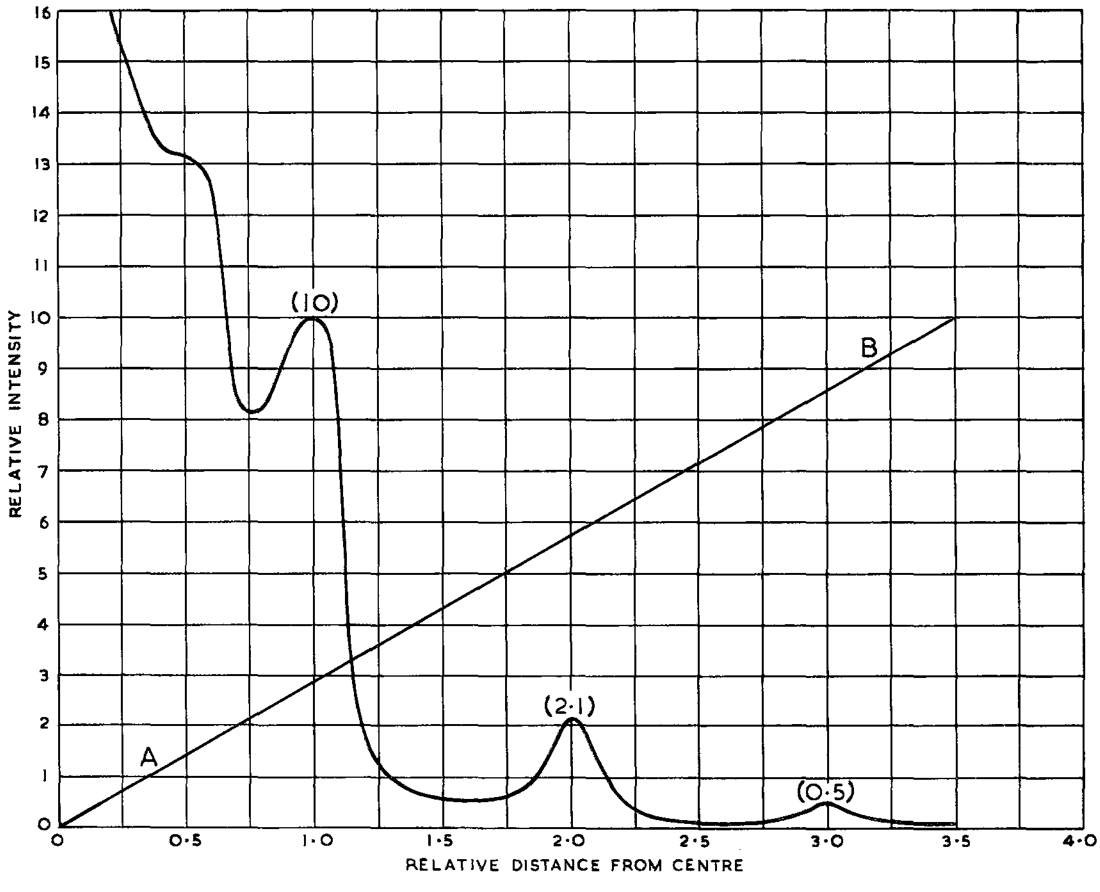


Fig. 1 - Measured intensity profile of the ring pattern produced by a small spot of excited phosphor

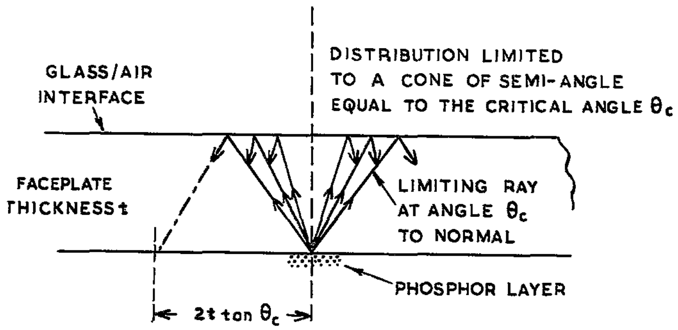
3. ANALYSIS OF PROFILE FORM

The distribution of light flux within the faceplate, due to a luminous element of phosphor in partial contact with it, is rather complex. An exact theoretical analysis of the photo-mechanism leading to such a distribution is beyond the scope of this report. A coarse analysis, however, shows that the radial flare intensity profile (see Fig. 1) is basically synthesized by the addition of two distinct light flux distributions emanating from the luminous phosphor spot. The distributions are:

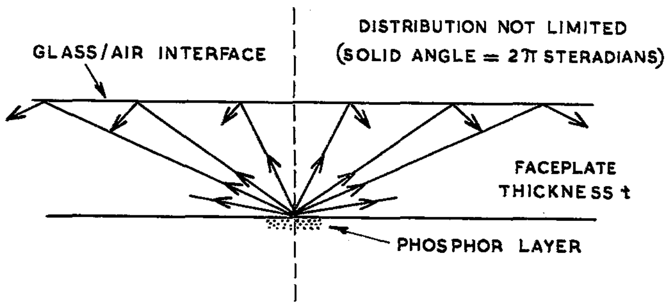
(i) that arising from the fraction of the luminous phosphor spot which is in intimate (i.e. optical) contact with the faceplate, and

(ii) that arising from the remainder, which is not in optical contact.

These distributions are illustrated in Figs. 2(a) and 2(b) where it can be seen that the light flux from the fraction not in optical contact (Fig. 2(a)) is restricted to a cone of semi-angle equal to the critical angle θ_c, of the glass/air interface. The flux emanating from the fraction *in* optical contact (Fig. 2(b)) is distributed over the total solid angle (2π steradians). (In conventional cathode-ray tubes the amount of phosphor contact is usually less than 30 per cent.*) The light flux specularly reflected by the glass/air interface gives rise to flare by illuminating the phosphor, which behaves as a diffuse reflector. Those rays which are reflected at θ_c or greater illuminate only the fraction of phosphor in optical contact, the remainder being again specularly reflected.



(a)



(b)

Fig. 2 - Basic internal flux distributions:

(a) Distribution due to the fraction of phosphor not in optical contact with the faceplate

(b) Distribution due to the fraction *in* optical contact

*It was estimated by measurement on the particular tube used for the intensity determination that there was 14% phosphor contact.

If we consider a single reflection of the light incident on the glass/air interface it is clear that the radial intensity profile of the halation ring system is comprised of two components, one of which (due to phosphor not in optical contact) terminates at a distance from the luminous centre given by $2t \tan \theta_c$, where t is the faceplate thickness.

It can be shown that the intensity of the second and subsequent specular reflections of a particular light ray is exceedingly small (<<1% of the first reflection) except for those rays which strike the glass/air interface with angles of incidence near to or greater than the critical angle θ_c, where the internal reflection coefficient is not small. (See Fig. 5.) This means that the radial intensity profile at and beyond the first ring is determined mainly by the light flux which emanates from the phosphor in optical contact, since the other flux component terminates at θ_c. The second and subsequent concentric halation rings of the system have radii which are integral multiples of $2t \tan \theta_c$, and are explained by the train of successive specular reflections of rays initially inclined at or near the critical angle. These equally spaced peaks of intensity in the profile are superimposed on a background intensity due to initial rays incident at angles greater than θ_c.

4. INTEGRATION FOR LARGE-FIELD CONDITIONS

Having determined the intensity distribution of flare originating from a small element or spot, it is possible to deduce the integrated effect of the flare when a large area or field is illuminated. The contrast limitation imposed by flare usually becomes more serious for that type of displayed picture which consists of small "black" areas surrounded or flanked by large "white" areas. The simplest case to treat analytically is the relative flare illumination at the centre of a circular unexcited phosphor patch surrounded by uniformly excited phosphor, as indicated in Fig. 3.

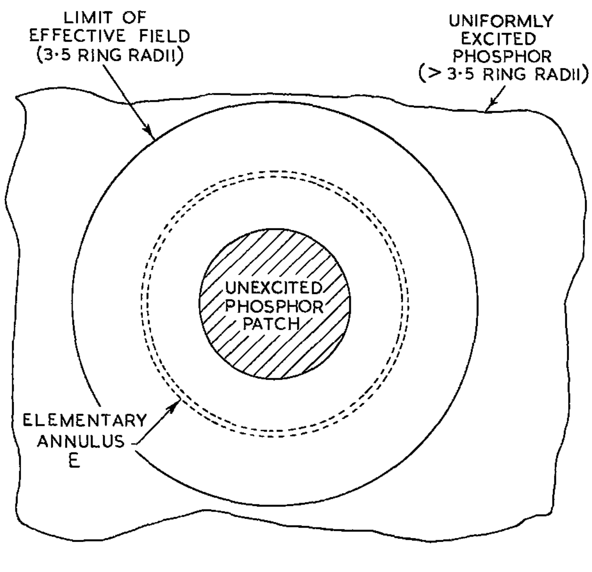


Fig. 3 - Illustrating the method of integration for large-field conditions

The first step is to deduce the contribution to the total flare at the centre by elementary annuli concentric with the unexcited phosphor patch (such as the annulus E in Fig. 3). This is equivalent to weighting the measured profile of Fig. 1 by a straight line (AB in Fig. 1), since the areas of the various elementary annuli comprising the surrounding field are proportional to their radii. The area-weighted relative intensity profile which is then obtained is shown by curve A in Fig. 4. It will be seen that a large proportion of the central flare derives from the region enclosed by the first ring. Further, as the diameter of the unexcited patch is increased, the central flare intensity will diminish at an increasing rate until the first ring diameter has been exceeded, when it will then diminish at a slower rate.

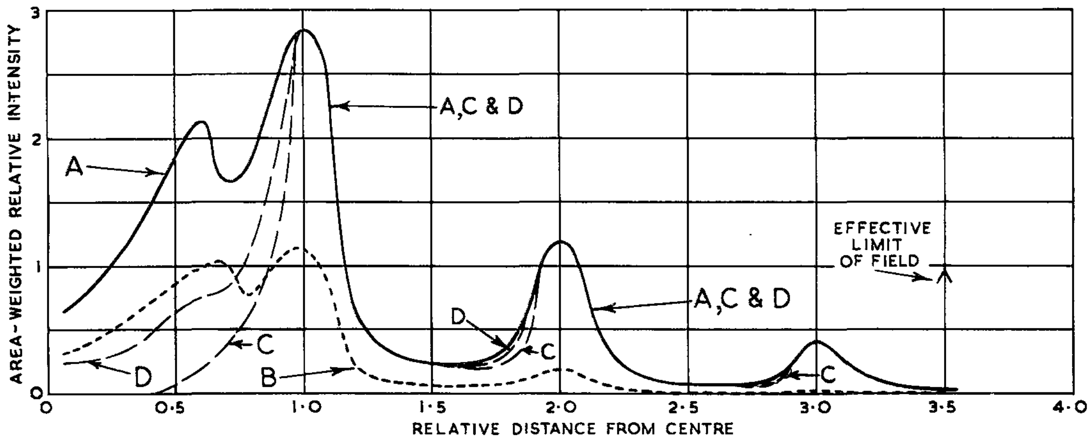


Fig. 4 - Area-weighted flare intensity profile and the deduced effect of the flare-reducing methods

A - Untreated faceplate
B - Light-absorbing faceplate (T = 71%)
C - Glass/air surface "perfectly bloomed" with single layer
D - Typical single-layer "blooming". (Glass refractive index = 1·52)

To obtain the central flare intensity for a patch of given radius, it is only necessary to measure the area under the profile in Fig. 4 between this radius and the effective limiting radius (taken to be 3·5 units) of the surrounding field.

5. FLARE-REDUCING METHODS

5.1 "Blooming"

One way of reducing the internal reflection coefficient of the glass/air interface is to apply one or more vacuum-deposited, anti-reflection coatings to the surface, as is done with optical lenses. The internal reflection coefficient of treated and untreated glass surfaces has been computed for a range of internal angles of incidence. The results are shown in Fig. 5. Curve A (full-line) is for an untreated faceplate. Curve B refers to a single-layer, anti-reflection coating on glass: the coating is assumed to be magnesium fluoride, which is used commercially for this purpose, having a refractive index of about 1·38. Curve C is for a hypothetical single-layer coating whose refractive index is made equal to $\sqrt{N_g}$, where N_g is the refractive index of the glass, in order to ensure perfect matching at normal incidence. A value of N_g = 1·52 has been used in these calculations. (It should be remembered that with single layers these calculated reflection coefficients are theoretical minimum values, which hold strictly only for monochromatic light.)

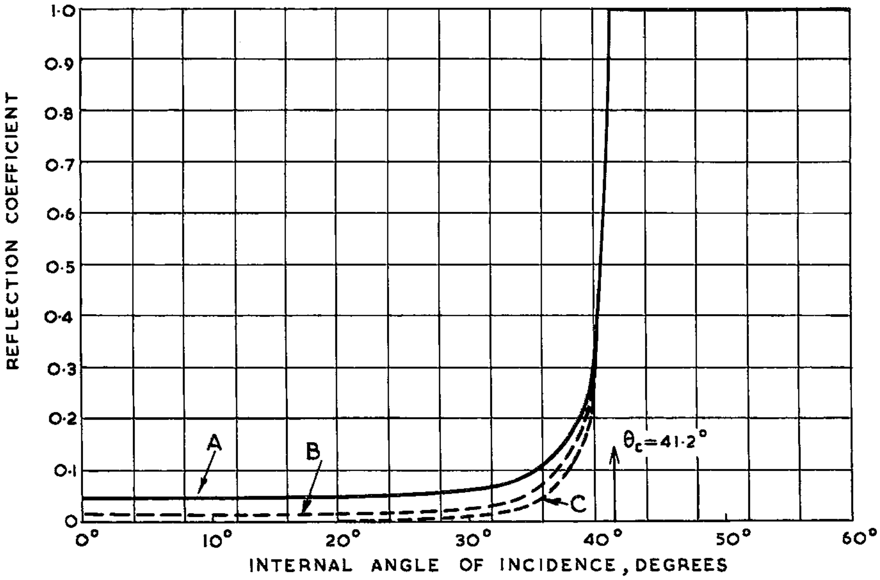


Fig. 5 - Theoretical reflection coefficient plotted against the internal angle of incidence

A - Untreated glass/air interface (Refractive index = 1·52)
B - Typical single-layer "blooming"
C - Single-layer "blooming" (perfect match)

It can be seen from these results that "blooming" with transparent dielectric materials becomes substantially ineffective at two or three degrees below the critical angle,* even if we assume that perfect matching can be achieved and that we are concerned only with monochromatic radiation. The unity reflection coefficient at the critical angle and beyond is unaffected by surface treatment, so that complete elimination of flare by "blooming" is not possible in conventional cathode-ray tubes which have partial phosphor contact.

The dashed curves C and D in Fig. 4 show the modified profile to be expected when the faceplate is "bloomed perfectly" and with a single layer of magnesium fluoride, respectively.

The profiles C and D were obtained by modifying curve A to take account of the reduced reflection coefficient at the glass/air interface. In order to do this, it was assumed that the second and third superimposed peaks of the profile are due to light which has been specularly reflected, at the glass/air interface, two and three times, respectively, and that the remainder of the profile is due to a single reflection. This procedure follows from the analysis in Section 3.

* For glass of refractive index 1·52 the critical angle is 41·2°.

5.2. Absorbing or Tinted Faceplate

This method can take the form of a thin light-absorbing layer of material in optical contact with the faceplate (refractive indices matching), or the latter can itself be light-absorbing. In either case, the flare light illuminating the phosphor as a result of reflection at any angle is reduced in intensity by a factor always greater than T^2, where T is the internal transmission factor normal to the faceplate. The light rays reaching the phosphor after reflection are increasingly attenuated as their angle of incidence on the glass/air interface increases, owing to the greater distance travelled by the more oblique rays through light-absorbing medium. Further, the equispaced peaks in intensity found in the flare profile, which establish the concentric ring pattern, are due to those light rays which strike the faceplate interfaces (front and rear) at angles of incidence close to the critical angle; so that the second ring of the system is due to light which has traversed the faceplate four times. Hence, with an absorbing faceplate, the ring pattern rapidly disappears beyond the first ring.

Fig. 6 shows the attenuation of the intensity of the reflected light (single reflection), relative to that of a non-absorbing faceplate, plotted against internal angles of incidence. The full-line curve B is for a faceplate having an internal transmission factor of 71%, and the broken line curve B′ for one of 79%. The improvement in the flare intensity profile (deduced from curve B in Fig. 6) due to an absorbing faceplate having an internal transmission factor of 71% is shown by the dashed profile B in Fig. 4. This modified profile is obtained from curve A, Fig. 4, using the same assumption about the synthesis of the profile form stated in Section 5.1.

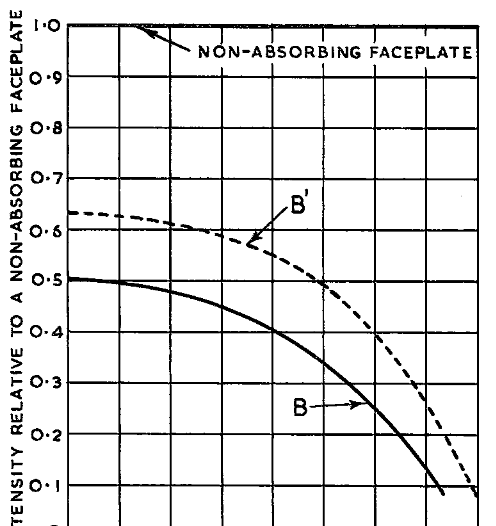


Fig. 6 - Attenuation of the (once) reflected light, due to an absorbing faceplate, plotted against internal angle of incidence

Curve B, $T = 71\%$ Curve B′, $T = 79\%$

6. CONCLUSIONS

The relative flare intensity at the centre of a circular unexcited phosphor patch has been computed for a number of patch radii by the method indicated in Section 4 using the estimated profiles given in Fig. 4. The results are shown in Fig. 7, where it can be seen that the reduction of flare intensity due to "blooming" techniques (curves C and D) is confined to small area patches and that the reduction due to an absorbing faceplate (curve B) extends over the whole range of patch radii. Curve A refers to an untreated non-absorbing faceplate.

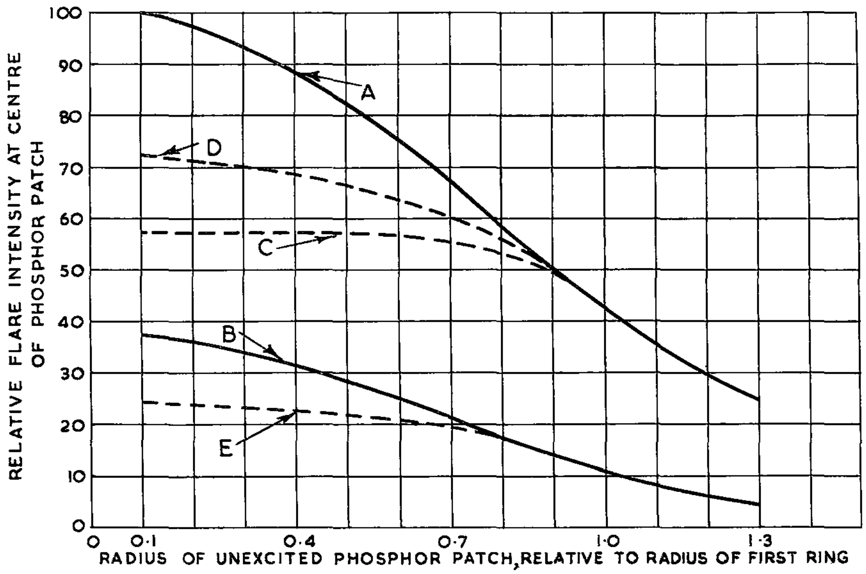


Fig. 7 - Deduced relative efficiencies of the flare-reducing methods for various radii of unexcited phosphor patch

A - Untreated faceplate
B - Light-absorbing faceplate (T = 71%)
C - Single-layer "blooming" (perfect match)
D - Typical single-layer "blooming"
E - Combined "bloomed" and absorbing faceplate (T = 71%)

The efficiency of the flare-reducing techniques discussed, averaged with respect to the size of patch, can be estimated from the relative areas under the computed curves of Fig. 7. It would appear that the average efficiency, i.e. the reduction in flare intensity at the centre relative to the flare intensity with an untreated faceplate, (over the range 0·1 to 1·3 ring radii) of the "blooming" method is limited to about 25% with the particular tube investigated. This limiting figure will depend, in other tubes, on the actual amount of phosphor contact: if the contact fraction is high the efficiency of the "blooming" method will be low and vice versa. The average flare-reducing efficiency achieved with an absorbing faceplate, having an internal transmission factor of 71% (curve B in Fig. 7), is approximately 68%. The efficiency, in the case of an absorbing faceplate, is not greatly influenced by the amount of phosphor contact. Clearly the efficiency of an absorbing faceplate is a function of the amount of absorption (i.e. of its transmission factor) and, if a low brightness could be tolerated, the flare intensity could be reduced to a very low value.

Curve E in Fig. 7 is the case for a combined "bloomed" and absorbing faceplate, which shows that the extra improvement due to "blooming" is not great.

It should be remembered that the improvements in flare intensity relative to that of an untreated faceplate have been discussed on an objective scale. Subjectively, therefore, the improvements might have greater or less significance. Nevertheless,

it does appear that the most efficient method of tackling the problem of flare in conventional cathode-ray tubes is to use an absorbing faceplate.

7. REFERENCES

1. Law, R.R., "Contrast in Kinescopes", Proc. I.R.E., Vol. 27, pp. 511/524, August 1939.

2. Haines, J.H., "Contrast in Cathode Ray Tubes", Tele-Tech, Vol. 12, No. 6, pp. 100/102, 179/180, June 1953.

3. "An Assessment of Flare in the Film Telerecording Process", Designs Department Technical Memorandum No. 7.21(57).

MV